1.5 Learning from Acid Deposition

Figure B1.44: Sulfur stockpiles are the result of using technologies that remove sulfur from natural gas and other petroleum sources.

Thus far, you have seen that a great deal of knowledge, both chemical and general, is required to understand the issue of acid deposition. Earlier, you were asked to identify intended and unintended aspects of human activity and use of technology. When you think about preventing acid deposition, the obvious solution is to remove acid-forming substances from emissions. But what do you do with the products?

Sulfur is also stockpiled from oil sand refined near Fort McMurray. Each year, 15 million tonnes of sulfur is removed from oil sand. What is done with all that sulfur? Does sulfur removal actually help reduce acid deposition?

In this lesson you will discover how tackling the problem of acid deposition not only involves the use of technology, it also involves all parts of society: local and international governments, industries, and individuals.

Practice

52. It is estimated that up to 5% of the mass of oil sand mined is sulfur and that 15 million tonnes of sulfur each year are produced by sulfur-removal processes used in the oil sands. Estimate the mass (in tonnes) of oil sand mined yearly.

Reducing Acid Deposition

Theories about acid deposition and its effects on the environment have changed over time as new evidence has accumulated. At one time, it was believed that dispersing sulfur-dioxide emissions from the smelting of nickel higher in the atmosphere using a superstack (like the one in Figure B1.45) would decrease the occurrence of acid deposition. Unfortunately, the hypothesis was not supported when evidence of acid deposition began to appear in areas over 200 km from the smelter.

Currently, a variety of technologies are used to reduce emissions. Evidence collected from studies of lakes in Ontario and other regions affected by acid deposition have shown the following:

- Reducing emissions is necessary for areas exposed to extreme acid deposition to recover.
- Areas exposed to extreme levels of acid deposition will recover, but it is a long process.

Figure B1.45: The 380-m tall superstack in Sudbury, Ontario, was the world's tallest chimney when it was built in 1972.

Try This Activity

Catching Emissions

Science Skills

✓ Analyzing and Interpreting

Purpose

You will determine a method of catching emissions.

Materials

- long, plastic tube (e.g., golf-club tube at least 30 cm long)
- electric hair dryer (at least 1000 W)
- plastic grocery bag
- metre-stick
- Styrofoam chips (or confetti or black pepper)
- 10-cm length of transparent tape (or elastic band)

Procedure

step 1: Hold one end of the plastic tube about 3 cm above a small pile of Styrofoam chips.

step 2: Use your other hand to turn on the hair dryer, and position the airflow across the top of the tube. Operate the hair dryer for one minute.

step 3: Observe the effect the air current has on the material at the other end of the tube.

step 4: Once the minute is up, turn off the hair dryer and inspect the inside of the tube.

step 5: Wrap the plastic bag around the end of the metre-stick to make a ball small enough to fit inside the plastic tube. Use the tape to fasten the bag to the metre-stick so the plastic bag stays in place.

step 6: Insert the end of the metre-stick with the bag attached into the plastic tube. Move the bag back and forth along the inside of the plastic tube for 1 min.

step 7: After 1 min, remove the metre-stick (and the plastic bag) from the plastic tube and repeat steps 1 to 3.

step 8: Clean the inside of the tube as instructed by your teacher, and return all materials to their proper place.

Science Links

Transferring charges onto the surface of the plastic tube causes the charged particles drawn up the tube to be attracted to the inside walls, stopping the particles' movement. In Unit C you will learn more about electric charges and fields and how substances moving against each other often cause a transfer of electrons.

Analysis

1. Describe the effect that the air from the hair dryer had on the material at the lower end of the tube.
2. Describe the effect that moving the plastic bag through the tube had on the material located at the lower end of the tube when you repeated the procedure.
3. Provide an explanation of the results observed.

Reducing Emissions—Electrostatic Precipitation

Did you notice in the "Catching Emissions" activity that the material drawn into the tube stuck to the walls after the plastic bag was moved through the tube? What effect did transferring a charge onto the tube have on the particles drawn up the tube?

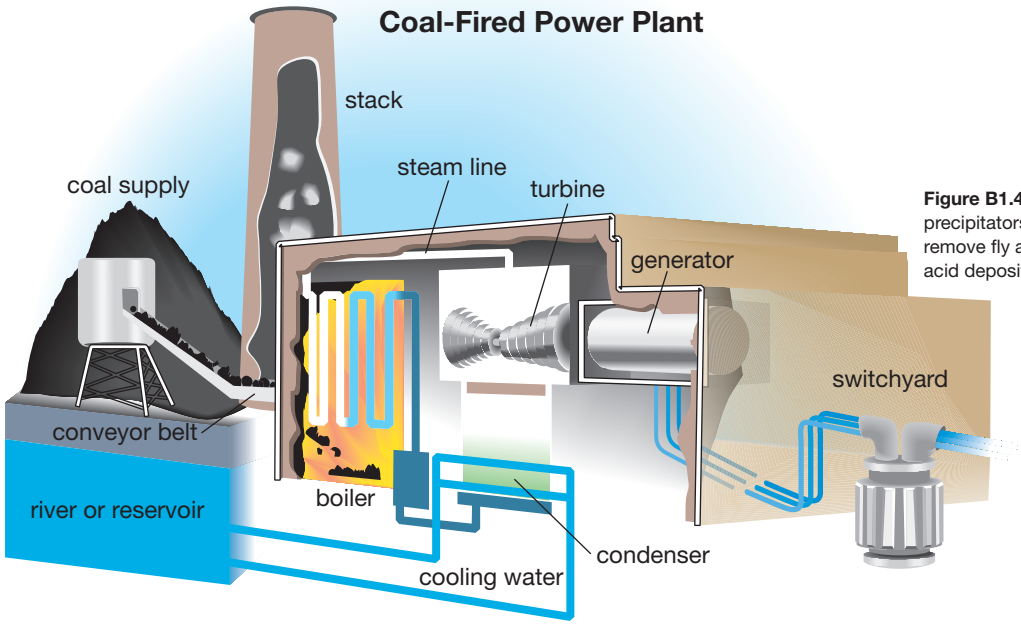


Figure B1.46: Electrostatic precipitators can be used to remove fly ash containing dry acid deposition.

The coal combusted in a coal-fired power plant contains a small volume of sand. Although the combustion reaction does not chemically change the sand, smaller particles of sand are released from the combustion chamber and leave the stack as **fly ash**. Recall that SO_2 and NO_x can be absorbed into the surface of substances, including fly ash. This makes fly ash a potential source of dry acid deposition.

- **fly ash:** small particles of sand and other unburned material that remain suspended in the exhaust gases when pulverized coal is combusted
- **electrostatic precipitator:** a device that uses electric fields to collect fly ash from emissions

In a process similar to the "Catching Emissions" activity, fly ash is removed from the gases that travel up the stack by an **electrostatic precipitator**. As the particles of ash move into the precipitator, they are exposed to two electrodes. Particles of fly ash become negatively charged as a result of their contact with the negative electrode. Once the fly ash is negatively charged, it will be attracted to and stick to the positively charged plates within the precipitator.

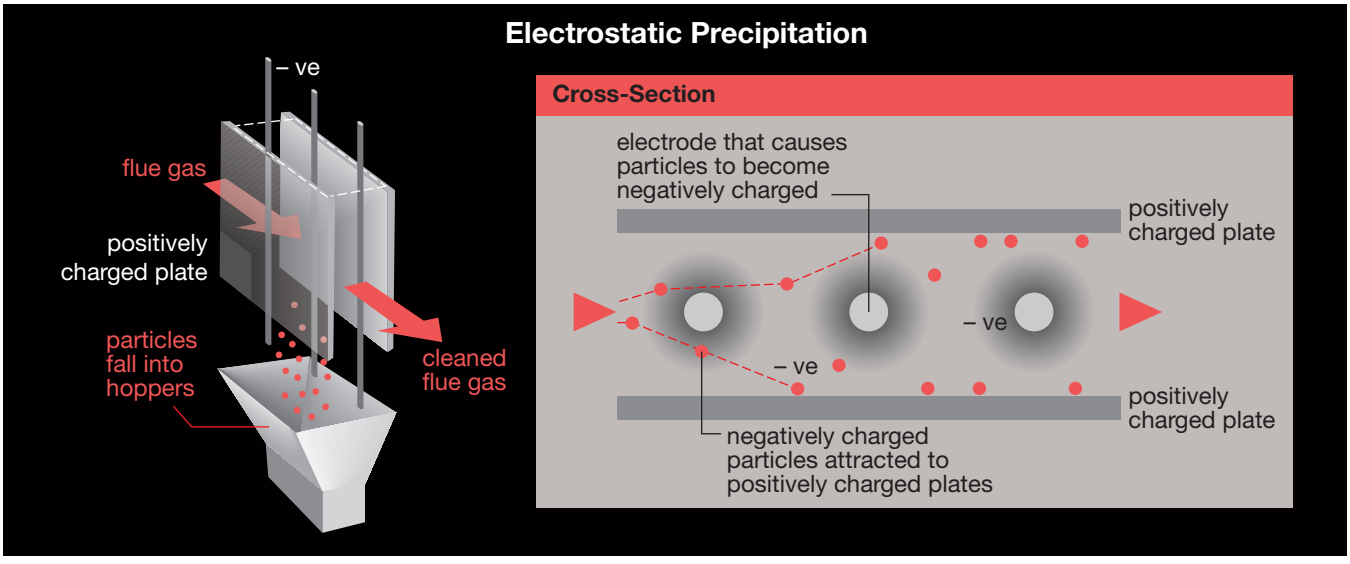


Figure B1.47: An electrostatic precipitator collects fly ash to reduce particulate emissions and acid deposition.

Electrostatic precipitators not only greatly reduce the release of dry acid deposition absorbed onto fly ash, they also reduce particulate emissions. Recently, greater attention has been paid to particulate emissions because evidence has shown that they are a cause of the increased numbers of cases of asthma and other breathing difficulties.

Reducing Emissions—Scrubbing Emissions

When the smoke from the combusted coal was bubbled into water, it rapidly changed the colour of the indicator in the water. **Scrubbing** is a process used to remove one or more gases from a mixture of gases. Scrubbers are used to remove $SO_2(g)$ produced by the combustion of coal.

What kind of substance would you place into the scrubber to remove $SO_2(g)$? Perhaps the next demonstration will help you answer this question.

scrubbing: a process used to remove one or more components from a mixture of gases by passing it through substances that absorb and separate unwanted components

Investigation

Testing Scrubbing Materials—Demonstration

Science Skills

✓ Analyzing and Interpreting

CAUTION!

The procedure should be performed by your teacher.

Purpose

You will watch a demonstration that tests the ability of substances to remove acid-forming compounds from smoke.

Materials

Set up the materials as shown in Figure B1.48.

Figure B1.48

- 0.100-mol/L NaCl(aq)
- 0.100-mol/L NaOH(aq)
- 0.100-mol/L Na_2CO_3(aq)
- 0.100-mol/L NH_3(aq)
- $CaCO_3$(s)

Procedure

Observe and compare the results for each of the trials performed with the solutions listed. Observe and compare the results of the trial using the solid substance with the results obtained from the trials using the solutions.

Analysis

1. Explain how you were able to determine whether the substance tested was able to reduce the amount of acid-forming substances in the gas.
2. Rank the substances tested in terms of their decreasing ability to remove acid-forming substances from the gas collected.
3. Using your knowledge of chemistry, explain which type of substance appeared to be best at removing acid-forming substances.
4. If the solutions represent a wet-scrubbing process and the solid represents a dry-scrubbing process, compare the efficiency of wet and dry scrubbers at removing acid-forming substances from the gas collected.
5. Do you feel the procedure in this demonstration allowed for valid comparisons to be made among the substances tested and between the use of solutions and solids as materials for scrubbing? Support your answer by citing specific examples.

Many substances are capable of scrubbing or absorbing acid-forming emissions. Did you notice in the demonstration that the best scrubbers were bases—the substances containing hydroxide ions, carbonate ions, and ammonia? All of these substances are used in industrial scrubbers because of their ability to react with acids. Calcium carbonate is a popular scrubbing compound because of its abundance and because it is a weak base. Safety concerns associated with the use of hydroxides (e.g., highly corrosive) and ammonia (e.g., strong, pungent odour) restrict the use of these substances as scrubbers.

The design of a scrubber is quite simple. Refer to Figure B1.49. Exhaust gases enter the bottom of the tower. At the top of the tower, the liquid containing the material that will absorb components from the exhaust gases is added. The gases and the scrubbing compounds meet within the tower and the reaction between the two substances completes the scrubbing process.

Cross-Section of a Scrubber

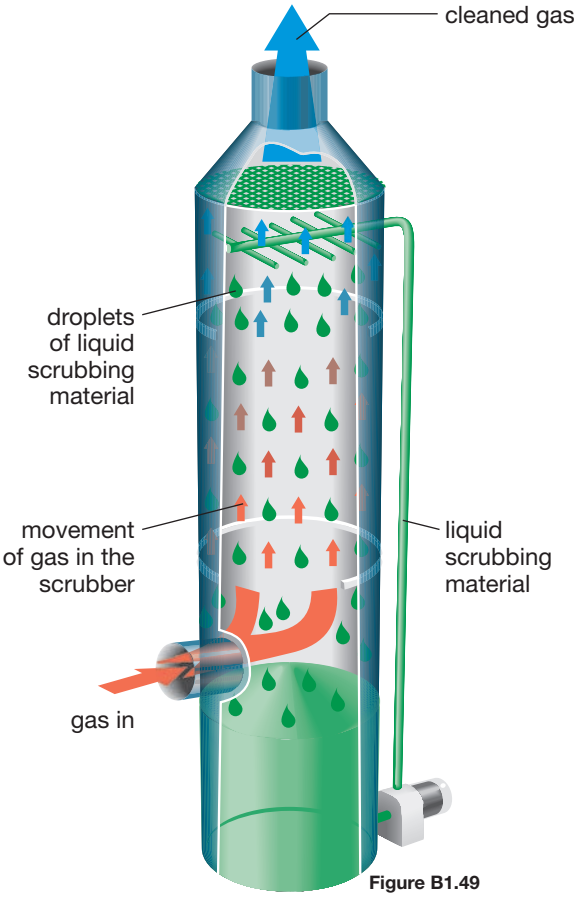


Figure B1.49

Many of the materials used in scrubbers to remove SO_2 are related. The metal-refining industry depends highly on the use of scrubbers that contain lime (calcium oxide) to remove sulfur dioxide produced during the refining of metal ores. Lime (calcium oxide) is produced by the heating of calcium carbonate. Both substances also have basic properties. Kilns, like the one pictured in Figure B1.50, are used to heat calcium carbonate to produce lime.

DID YOU KNOW?

Kilns measuring up to 200 m in length operate at temperatures above 1400°C to convert limestone into lime, which is used in the production of cement. To produce such high temperatures, a large quantity of coal or natural gas is required. The cement and other industries that utilize combustion processes use technologies, like scrubbers, to control emissions.

Figure B1.50: This kiln at Lehigh Inland Cement in Edmonton is over half the length of a football field and 4.2 m in diameter.

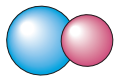
DID YOU KNOW?

The reaction between SO_2 and limestone in a scrubber can be used to produce calcium sulfate, $CaSO_4(s)$, commonly known as gypsum. Gypsum is used in a variety of building materials, like drywall. Many industrial processes are being designed in such a way that waste materials may be used for other processes.

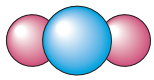
Reducing Emissions—NO_x

Recall that NO_x is an abbreviation for two oxides of nitrogen: NO(g) and NO_2(g). Because of differences in the chemical properties of these two compounds, it is difficult to remove both compounds using a scrubber. A more efficient method for removing NO_x compounds from the exhaust of combustion reactions involves the use of a **catalyst**.

NO_x Compounds



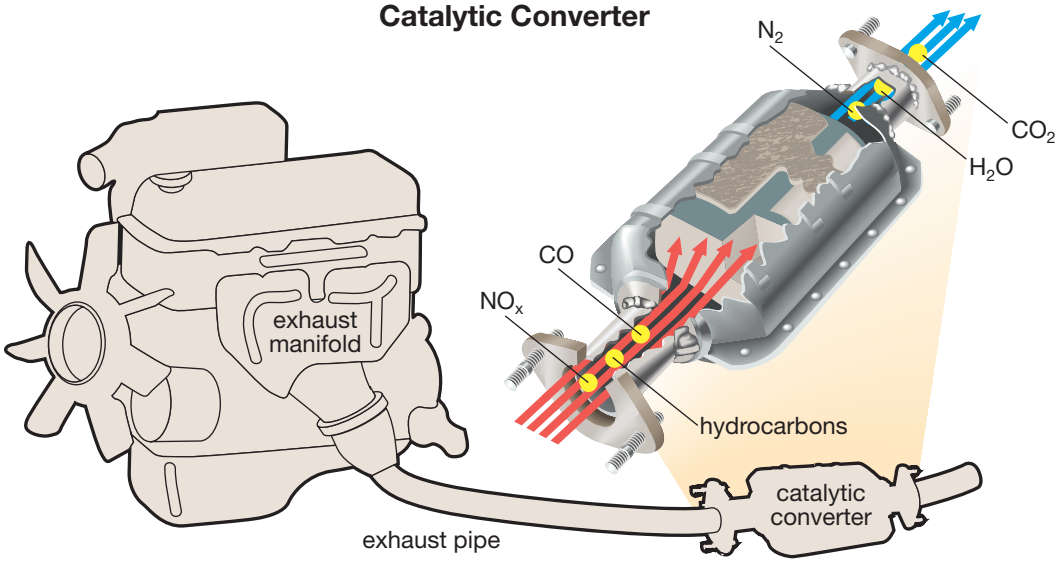
N = O
nitrogen monoxide, NO



O = N − O
nitrogen dioxide, NO_2

The transportation industry, including automobiles, is a major source of acid deposition because of the NO_x emissions produced by the internal combustion engine. The high temperature at which combustion occurs within an engine causes a reaction between atmospheric nitrogen and oxygen that produces NO_x.

Catalytic Converter



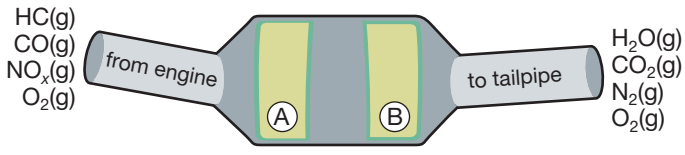
catalyst: a substance used in a chemical process that increases the speed of the reaction and is not affected by the process

catalytic converter: an emission-control device used to remove NO_x, carbon monoxide, and hydrocarbons from vehicle exhaust

One of the purposes of a **catalytic converter** is to change NO_x compounds into nitrogen. Automobile exhaust containing NO_x, carbon monoxide, and small hydrocarbon molecules undergoes reactions in the presence of the catalysts within the converter to produce N_2(g), CO_2(g), and H_2O(g). Catalytic converters were first used in automobiles in the 1970s as a pollution-control device. Further development of the technology has resulted in converters becoming more efficient in removing pollutants from exhaust. Converters are used in vehicles fuelled by gasoline, diesel, propane, and natural gas.

Large industry also uses catalysts to remove NO_x compounds from emissions.

Catalytic Converter Process



Ⓐ Reduction

NO_x, CO → N_2 + CO_2

Ⓑ Oxidation

HC, CO, O_2 → H_2O + CO_2

Figure B1.51: The reactions within a catalytic converter change NO_x and other substances of concern into less harmful substances.

Figure B1.52: Concerns regarding emissions where vehicles are used indoors have prompted the development of catalytic converters for vehicles like this forklift, which operates on propane.

DID YOU KNOW?

The actions of drivers can have a significant effect on emissions. When catalytic converters were first fitted on vehicles, concerns about the reduction in the horsepower cause many people to remove them from their vehicles. Even with more efficient models of catalytic converters, drivers cause significant levels of emissions by excessive idling, such as waiting in line at a drive-through.

Photochemical Smog

Imagine you've been sitting indoors all day. You are looking forward to getting outside and doing some sort of physical activity, whether it be playing soccer, running, or walking. But when you look out the window toward the horizon you notice a brownish haze in the sky. You may begin to wonder what that haze is and whether it is even safe to exercise outside.

The brownish haze is $NO_2(g)$ collecting in the **troposphere**. This brownish haze is often referred to as **photochemical smog**. Photochemical smog occurs most often in major cities, where higher levels of automobile exhaust and emissions of hydrocarbons and NO_x compounds occur.

Photochemical Smog Reaction 1

Within car engine: $N_2(g) + O_2(g) \rightarrow NO(g)$

In atmosphere: $2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

The brown haze, $NO_2(g)$, is the result of NO(g)—produced by the reaction of nitrogen and oxygen in vehicle engines—that is quickly converted into $NO_2(g)$ once it is released into the atmosphere. The photochemical smog reaction doesn't stop at $NO_2(g)$. Sunlight can cause a further reaction. Sunlight is composed of wavelengths of radiation with different energies. Some of these wavelengths have sufficient energy to convert $NO_2(g)$ back into NO(g) and a single oxygen atom.

Photochemical Smog Reaction 2

$$NO_2(g) \xrightarrow[\text{sunlight}]{\text{energy from}} NO(g) + O(g)$$

oxygen atom

Now, a single oxygen atom is highly reactive and will combine with oxygen in the troposphere to form ozone.

Photochemical Smog Reaction 3

$$O(g) + O_2(g) \rightarrow O_3(g)$$

Note: This reaction involves another substance, like $N_2(g)$, present in the atmosphere to act as a catalyst.

Normally, ozone is considered to be beneficial as a filter to protect Earth from ultraviolet radiation; but that is when it is located in the stratosphere, not the troposphere. Ozone is toxic to organisms at high concentrations. At lower concentrations, like those present in photochemical smog, it irritates your eyes, nose, and throat. Hot, windless days during summer can contribute to higher levels of ground-level ozone, causing asthma, bronchitis, coughing, respiratory infections, and decreased lung performance. On such days, smog advisories might be issued to inform you that exercising outdoors is not recommended.

Figure B1.53: Toronto (bottom) shows a thicker layer of photochemical smog than Calgary (top). The city of Calgary, along with many other highly populated urban areas is working hard to avoid the air-quality problems that the city of Toronto is experiencing.

- **troposphere:** the lowest region of the atmosphere that extends to approximately 18 km above Earth's surface; the region of the atmosphere where all weather occurs
- **photochemical smog:** a brownish-red haze produced by the reaction of sunlight and the components in automobile exhaust

DID YOU KNOW?

Information about air quality, including ozone levels, can be obtained form a variety of sources, like the television or the Internet. Alberta Environment updates air-quality information hourly and makes this information available at

http://www3.gov.ab.ca/env/air/AmbientAirMonitoring/currentairquality.html

Figure B1.54: The colour change along the edge of the leaf and the spots on the leaf are indicators of damage caused by ozone.

Although ground-level ozone is invisible, you can see quite easily the evidence of its effects. Some plants are extremely sensitive to ozone concentrations in the atmosphere and are used as bio-indicators. Materials like rubber, plastics, and paint are also affected by exposure to ozone. You may recall that rubber is composed of unsaturated hydrocarbon molecules. Ozone reacts with the multiple bonds between carbon atoms in unsaturated molecules, changing the properties of the rubber and causing it to lose its elasticity.

Volatile organic compounds (VOCs), including the hydrocarbons in exhaust and other organic molecules present in the atmosphere, can react with NO_x and ground-level ozone to produce peroxyacetyl nitrate, often referred to as PAN. The presence of PAN in the air is a concern because it is a strong irritant to the respiratory system.

volatile organic compound (VOC): a hydrocarbon or other organic molecule that vapourizes and exists as a gas in the air; sources include gasoline, solvents, paints, and other petroleum-based materials that vapourize

The catalytic converter is designed to reduce—not completely remove—hydrocarbons and NO_x emissions in vehicle exhaust. Since the occurrence of photochemical smog is directly related to automobile use, many major cities have initiated programs to reduce the number of vehicles on the road during morning and evening rush hour. These programs have made an impact on the severity of photochemical smog and the frequency of smog alerts in some areas.

Practice

53. Catalysts can become "poisoned" and lose their ability to function when exposed to certain substances. The catalyst within catalytic converters can be poisoned by the presence of lead and sulfur in gasoline. List other benefits that come from the removal of lead and sulfur from gasoline.

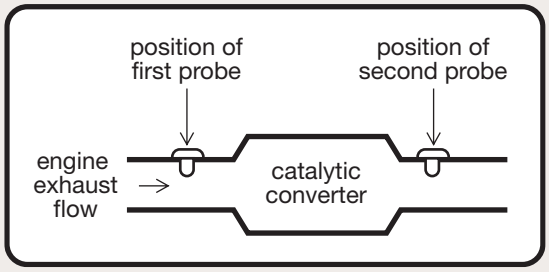
54. The pollution-reduction reaction that occurs within a catalytic converter is temperature sensitive. Better emissions reduction occurs when the catalytic converter operates at higher temperatures than at lower temperatures. Identify which driving behaviour listed below allows the catalytic converter to provide the best pollution reduction.

Driving Behaviours

- starting a car's engine 10 min before driving on a cold winter day
- waiting in the line at a drive-through with the engine running
- parking the car and turning off the engine while waiting to pick up a friend
- rapidly accelerating away from the curb after starting the vehicle

55. Explain how installing catalytic converters in vehicles that are used indoors can promote improved workplace safety.

56. During an emissions test, the function of an automobile's catalytic converter can be tested. To perform this test, probes are placed to detect the presence of substances in the vehicle's exhaust. One probe measures the amounts of substances in the exhaust before the catalytic converter, and the other probe measures the amounts of substances after the catalytic converter.



a. Identify whether the relative concentrations of CO, NO_x, and H_2O in the exhaust are high or low at the first and second probes.

b. In catalytic-converter testing, only a sensor that detects the amount of oxygen is normally used. Explain the rationale and the risks and benefits of using data regarding one substance in such a test.

Practice

57. Refer to Figure B1.55 when answering questions 57.a. to 57.d.

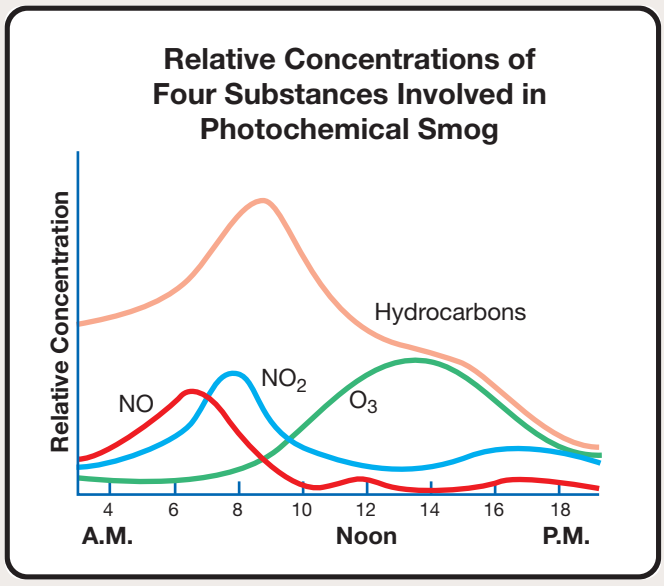


Figure B1.55

a. Explain the reason for the increase in the levels of NO and hydrocarbons early in the graph.

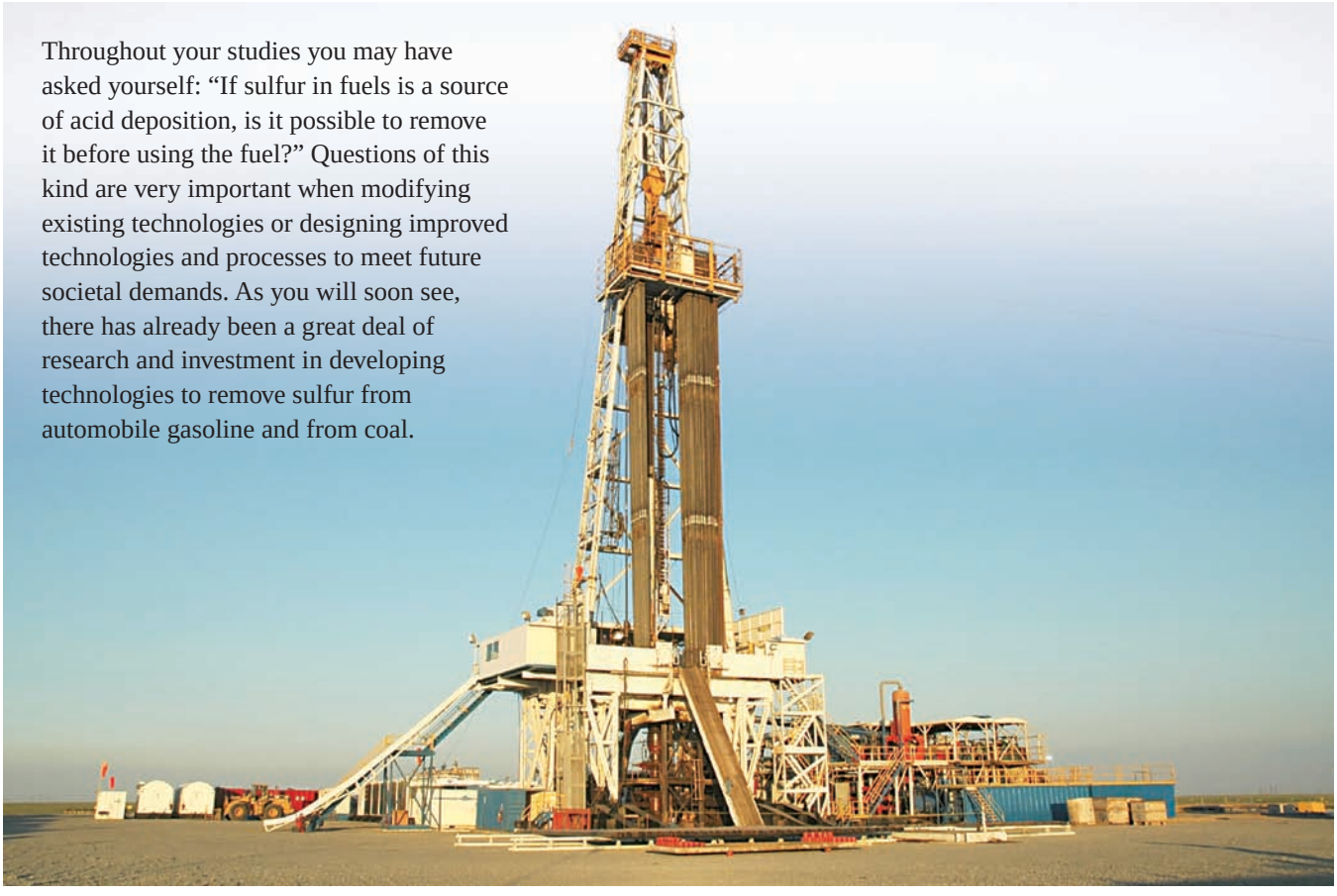
b. Explain why the highest concentration of NO_2 does not occur at the same time as the highest concentration of NO.

c. Explain why the concentration of O_3 rises in the afternoon when the concentrations of the other substances decrease.

d. Could a similar pattern of changing concentrations for these four substances occur in the late afternoon and evening after rush hour? Support your answer.

Reducing Emissions—Preventing the Production of SO_2, NO_x, and H_2S

Throughout your studies you may have asked yourself: "If sulfur in fuels is a source of acid deposition, is it possible to remove it before using the fuel?" Questions of this kind are very important when modifying existing technologies or designing improved technologies and processes to meet future societal demands. As you will soon see, there has already been a great deal of research and investment in developing technologies to remove sulfur from automobile gasoline and from coal.



Earlier, you learned about hydrogen sulfide, H_2S, that may be present in sour gas, natural gas, or petroleum deposits. Hydrogen sulfide is not only toxic, but it forms hydrosulfuric acid when dissolved in water. As you know, acids can contribute to the corrosion of metal. This creates additional problems at well sites. Many petroleum deposits begin to produce $H_2S(g)$ and, thus, become sour gas wells once they have been drilled. Research has identified that proper management of the water used at well sites can prevent wells from becoming contaminated with bacteria that converts the sulfur in the petroleum or natural gas which produces sour gas.

DID YOU KNOW?

Some species of bacteria can use the hydrocarbons in oil and natural gas as food. Oil companies support scientific research into the use of bacteria that consume petroleum and other hydrocarbons for cleanup and reclamation of sites where spills have occurred.

Emissions of NO_x can be prevented by altering conditions for combustion processes. You may recall that high temperatures within a furnace or combustion chamber of an automobile engine can provide sufficient energy for nitrogen and oxygen to combine. Two changes that have made considerable differences to NO_x emissions have been to

- use non-combustion processes where possible
- remove nitrogen from the combustion process by using oxygen instead of atmospheric air

Figure B1.56: Wind turbines are an example of a non-combustion process that can be used to produce electricity.

DID YOU KNOW?

Research enables modifications to the processes used to reduce emissions. The Claus process—invented over 100 years ago to remove sulfur from hydrogen sulfide to sweeten sour gas—has been modified many times. The SuperClaus process uses special catalysts to prevent the formation of SO_2. The Oxygen-Claus process uses pure oxygen to prevent the production of NO_x.

Recovering from Acid Deposition

Because ecosystems are so complex—involving the interaction of biotic and abiotic factors—recovery from acid deposition is expected to take a long time. Scientific data collected on lakes in Ontario that have experienced severe acidification demonstrated that the ecosystems have begun to show signs of recovery; but it is still a slow process.

liming: adding a basic compound to soil or a body of water to neutralize acid deposition

One method to assist in the recovery of lakes and/or soil that have become acidified is **liming**. Lime is calcium oxide, which is a basic compound. Other basic compounds that can be used include calcium carbonate, calcium hydroxide, and magnesium carbonate. Adding lime neutralizes the accumulated acid in the soil or water. By neutralizing the accumulated acid, liming immediately changes the pH of soil or water. Despite this immediate effect, can you think of a reason why liming is considered only a short-term solution to acidic deposition? Another problem with liming is the amount required. Calculations to determine the amount of lime to add and careful management during its application are important to ensure that an excess of the base is not added. An excess of base—and resulting alkaline pH—could create other undesirable effects.

Practice

58. Write the chemical formula for the bases used for liming.

59. Write a balanced chemical equation for the reaction describing the reaction between hydronium ions in the soil with the following bases.

a. magnesium carbonate

b. calcium hydroxide

Evaluating Needs and Technologies

Thus far, you have studied processes and actions that can be used to reduce emissions that can cause acid deposition. In the next activity you will study how many of these methods can be used together to achieve a purpose.

Utilizing Technology

Risks and Benefits of Clean-Coal Technologies

Background Information

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

The vast majority of the electricity produced in Alberta comes form the combustion of coal. Alberta has extensive low-sulfur coal reserves, but coal is considered to be one of the dirtiest fuels. Currently, there is much discussion about the development of a technology to reduce emissions produced by the combustion of coal. Zero-emissions or clean-coal technologies could provide a means for ensuring future energy supplies, maintaining (or even improving) environmental standards. There would also be economic benefits from the possible sale of the technology to other countries.

Question

Will investment in developing clean-coal technology benefit all Albertans?

Purpose

You will perform a risk-benefit analysis on the development of technologies that reduce emissions.

Procedure

step 1: Read the "Reducing Emissions from Coal" handout from the Science 30 Textbook CD. This handout describes the steps involved in developing clean-coal technology.

step 2: Read the article *Clean-Coal Advocates Seek Federal Funding for $33M Pilot Project* on the Science 30 Textbook CD.

step 3: Use the Internet to research the following focus questions:

- Will coal be required as an energy source in Alberta, in Canada, and throughout the world in the future?
- What is the projected impact on the environment if coal continues to be used in the future?
- What other technologies could be used to produce electricity if coal was not to be used?
- Is it possible to develop zero-emissions coal? Where do the emissions go? Would this result in improved environmental standards?
- Does it make sense for governments to invest in the development of the technology so that Alberta can become a leader in the development of clean-coal technology?
- What would be the local, national, and international impact of being a leader in the development of this type of technology?

Analysis

1. Use the steps listed in "Decision-Making Skills and Risk-Benefit Analysis" on pages 590 and 591 to perform a risk-benefit analysis to address the question stated following the background information.
2. Prepare a brief summary outlining the results of your risk-benefit analysis and your position regarding the research question you investigated.

Thinking Smart—Not Creating New Problems

Methods to address acid deposition have often relied on using technology. Scrubbers and catalytic converters are examples of these technologies. However, as you have seen, if the processes that generate emissions continue, the technology may not be enough. Technology cannot always fix problems, but changing processes and behaviours can.

Using public transport to reduce the number of cars on the road, changing driving habits, or using vehicles and equipment that do not rely on a combustion process can reduce emissions.

Figure B1.57: Participating in a car pool reduces the number of cars on the road at rush hour and reduces emissions contributing to photochemical smog and acid deposition.

DID YOU KNOW?

Plans for development prior to the 2010 Olympic Winter Games involve the use of 20 hydrogen-fuel-cell buses to service the Whistler area. After the Olympics, these buses will join the general fleet of buses, replacing the older diesel buses. Other plans to address environmental concerns associated with the development and hosting of the Olympics involve using fuel-cell-powered vehicles and building hydrogen filling stations between the major centres of Vancouver, Victoria, and Whistler.

Many major cities are using buses that utilize fuel cells—a technology you will study more in depth in Unit D. Fuel cells convert the chemical potential energy in hydrogen into electrical energy that powers an electric motor in the bus. This technology does not involve a combustion reaction and, therefore, does not produce emissions that contribute to acid deposition. However, there are questions regarding how hydrogen is produced and whether these methods make hydrogen a clean fuel.

Earlier, you saw a picture of the blocks of sulfur generated by the sulfur-removal processes used in refining oil sand. Some of the sulfur produced is sold to the manufacturers of fertilizers, pharmaceuticals, and other products; but a large excess cannot be sold. The stockpiles of excess sulfur have the potential to create environmental problems. Temperature extremes between winter and summer in the Fort McMurray area can cause the blocks of sulfur to erode and be carried by wind and deposit on surrounding soil. Deposited sulfur can be converted by bacteria in the soil into sulfuric acid. Possible negative effects such as soil acidification and possible changes to groundwater or surface water near the blocks are reduced by methods used to construct and monitor sulfur stockpiles.

Figure B1.58: Technicians use a variety of techniques, including video cameras, to determine the changes that occur to stockpiled sulfur.

Burying sulfur seems like an obvious solution to the problems caused by exposed sulfur piles, but careful study is required before burying sulfur is seriously considered as an option. Many factors, like temperature and moisture content of the ground and exposure to oxygen, can influence the growth of bacteria. Careful testing must ensure that proper conditions for storage occur. Both scientific and economic data for underground sulfur storage is being collected in order to make an informed decision regarding the use of this technology. How do you think scientific and economic data should be considered when making decisions about an environmental issue? You might want to look at the information that is available about this project and the scientific and economic data. You may also want to further discuss this issue with other students in your class.

International, National, and Individual Action

Throughout your study, you have seen that acid deposition is not only a problem in Canada. The United States and other industrialized countries have also been affected. Scientific evidence about substances that cause acidic deposition is quite clear—reducing emissions will result in a decrease in the occurrence of acid deposition and other environmental problems, like photochemical smog. Because wind currents can carry emissions across borders, international agreements between countries need to exist to protect the environment and people living in the countries affected.

Canada has participated in the development of a variety of international agreements relating to SO_2 and NO_x emissions. These include the

- 1985 United Nations Economic Commission for Europe Sulfur Protocol
- 1988 United Nations Economic Commission for Europe NO_x Protocol
- 1991 Canada-US Air Quality Agreement
- 1994 United Nations Economic Commission for Europe Sulfur Protocol

Since 1980, SO_2 emissions in Canada have been reduced by almost 50%, enabling Canada to meet its commitment to these international agreements. But, as you have seen, acid deposition is still a serious problem.

At the time this textbook was published, *The Canada-Wide Acid Rain Strategy for Post-2000* was the most recent document describing plans and actions to address acid deposition.

In Alberta, the development and use of plentiful fossil fuel resources has led to an increase in SO_2 and NO_x emissions, despite the extensive use of technologies that reduce emissions. Although this strategy acknowledges the opportunities for Alberta to develop these resources, it acts as a reminder of possible harm that may come to the environment. It may be only a matter of time before Saskatchewan and other provinces downwind of Alberta begin to demonstrate negative effects from acid deposition.

The strategy also identifies actions that each individual can take to help reduce SO_2 and NO_x emissions. Some of these actions include

- conserving energy by using public transport or alternative forms of transport, using more efficient automobiles, changing driving habits, and improving the insulation in your home
- supporting the development of technologies that produce electricity through non-combustion processes
- supporting processes that use technologies that reduce emissions
- recycling paper, metals, and plastics

1.5 Summary

In this lesson you discussed technologies used to reduce SO_2 and NO_x emissions. You also examined how the development of technology may indirectly cause other problems. You also discovered that solving the problem of acid deposition is a complex process that requires reductions in emissions to provide the opportunity for recovery. Canada's participation in international agreements and its development of a national strategy to address acid deposition have provided an opportunity for industry and individuals to take action to reduce emissions.

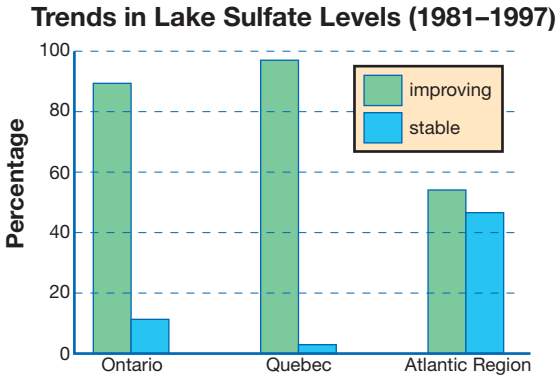
1.5 Questions

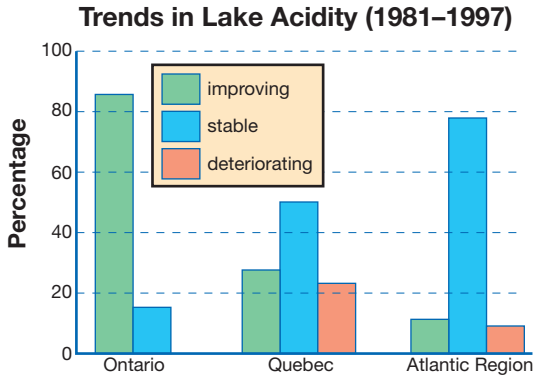
Knowledge

1. Make a list of activities that you and your family undertake that contribute to acid deposition.
2. Examine the list of personal actions that can be taken to reduce SO_2 and NO_x emissions on page 234. Explain how each of these actions could result in lower emissions.
3. Explain the conditions and substances necessary for the development of photochemical smog.
4. List the technologies that reduce SO_2 and NO_x emissions.

Applying Concepts

5. Use the following graphs to answer questions 5.a. to 5.e.





   a. Explain why sulfate levels can be used as a means to assess the level of acid deposition.
   b. During the period shown on the graphs, sulfur-reduction technologies were required to be used by industry in Canada. Identify which regions of eastern Canada appeared to benefit the most and which appeared to benefit the least from the use of these technologies. If possible, provide a possible explanation for the improvement and for the lack of improvement.
   c. What information would you want to see before making any conclusions as to whether the area was recovering?
   d. Explain what is meant by "Lake acidity is still deteriorating in some lakes" when referencing the "Trends in Lake Acidity (1981–1997)" graph.
   e. Is there a correlation between the information shown on the two graphs? Support your answer.

6. From March to May 1993, Calgary was the first Canadian city to have a voluntary emissions-testing program for vehicles. The SMOG FREE (Save Money On Gas From Reduced Exhaust Emissions) program offered free emissions tests and coupons for discounts on products, repairs, and services.
   a. List advantages and disadvantages of a program like SMOG FREE.
   b. Suggest possible reasons for the program to no longer exist.
   c. Predict whether a program like SMOG FREE would work today. Support your answer using examples.
7. Explain the benefits of being able to access current air-quality reports using the Internet or other technologies.
8. Use the Internet to determine the conditions necessary for a smog alert to be issued.
9. Is it necessary to invest funds on research and the development of technologies that reduce emissions to prevent acid deposition? Identify other ways the money could be spent.

Chapter 1 Summary

Producing electricity, driving automobiles, and other processes important to society create emissions that can have adverse effects on the environment and human health. Your study in this chapter has enabled you to identify substances contained in emissions from processes involving combustion and explain how these emissions can lead to acid deposition and other negative environmental effects. You also examined the technologies and changes to behaviour that help reduce emissions.

Studying the effects of acid deposition on the environment involves conducting experiments and collecting data about chemical and biological changes in the environment. Additional data about environmental change can be gathered by consulting those with traditional ecological knowledge. In Chapter 2 you will continue your study of organic compounds and their impact on society and their effects on the environmental.

Summarize Your Learning

This chapter focused on a variety of technologies, chemical terms, and chemical reactions and their impact on the environment. As you may recall, there are many complex relationships between these aspects. Managing the complex information you learned is much easier if you take some time to identify relationships within the information and organize it into some sort of pattern. Now that you have come to the end of this chapter, this is an appropriate time to focus on the patterns within the things you have learned.

Since the pattern has to be in a form that is meaningful to you, you have some options about how you can create this summary. Each of the following options is described in the Reference Section.

Option 1: Draw a concept map or a web diagram.	Option 2: Create a point-form summary.	Option 3: Write a story using key terms and concepts.	Option 4: Create a colourful poster.	Option 5: Build a model.	Option 6: Write a script for a skit (a mock news report).

Chapter 1 Review Questions

Knowledge

1. Use the following information to classify each substance listed as either acidic, basic, or neutral.

a. lake water with a pH of 7.9

b. gastric acid with a pH of 2.0

c. window cleaner with a hydronium-ion concentration of 2.23×10^{-10} mol/L

d. rust remover with a hydronium-ion concentration of 5.72×10^{-3} mol/L

2. Indicators can be used to measure the pH of a solution.

a. Explain how indicators can be used for this purpose.

b. Explain the level of precision that is attainable using indicators to measure pH.

c. Identify one technology that can be used to measure pH and provides better precision than indicators.

3. a. State the name of the theory that identifies acid-base reactions as involving the transfer of a hydrogen ion.

b. Identify which substance donates a hydrogen ion and which substance accepts a hydrogen ion during an acid-base reaction.

Applying Concepts

4. Complete the following reactions. Label the acid, the base, the conjugate acid, and the conjugate base in each reaction.

a. $HF(aq) + NH_3(aq) \rightarrow$

b. $HNO_3(aq) + HCO_3^-(aq) \rightarrow$

c. $H_3O^+(aq) + H_2BO_3^-(aq) \rightarrow$

d. $OH^-(aq) + HCO_3^-(aq) \rightarrow$

e. $CH_3COO^-(aq) + HS^-(aq) \rightarrow$

5. Methanoic acid is dissolved in water and produces a solution that has acidic properties.

a. Write the balanced chemical equation for methanoic acid and water.

b. Identify which product is responsible for the solution's acidic properties.

c. List the properties an acidic solution would have when tested using the apparatus you used in the investigations throughout this chapter.

d. Explain how empirical properties of acids and bases are useful when describing acids and bases.

6. Explain how rainwater can naturally have a pH of around 5.5.

7. Explain how rainwater can have a pH lower than 5.5.

8. Use the following information to complete the statement.

Solution	pH or $[H_3O^+(aq)]$
1	12.4
2	1.20×10^{-2} mol/L
3	4.5×10^{-9} mol/L
4	5.6

The four solutions in order from most acidic to least acidic are _____, _____, _____, and _____.

9. Refer to Figure B1.42 on page 219 to answer questions 9.a. to 9.e.

a. Explain why many monitoring stations are used in Alberta.

b. Review the locations of the precipitation-quality monitoring stations shown on the map. Identify monitoring stations that are located near activities that may have an effect on the environment.

c. List the kinds of measurements that are made during precipitation-quality monitoring. Explain the significance of these tests.

d. Explain how the locations of the monitoring stations provide information about acid deposition in Alberta.

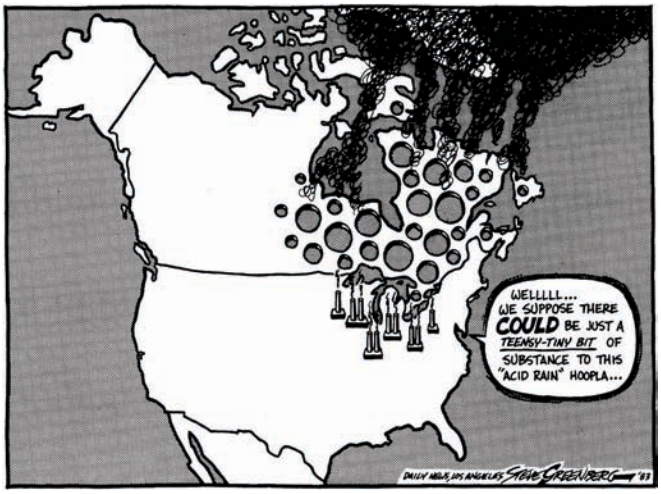
e. Explain how the monitoring stations in these locations may not provide sufficient data regarding the effects of acid deposition in Alberta.

10. Refer to the cartoon to answer questions 10.a. to 10.c.

a. Identify the issue the cartoon is addressing.

b. Use your scientific knowledge to explain the issue identified in the cartoon.

c. Identify aspects of the cartoon that may be misleading.



11. "The solution to pollution is dilution." Use your knowledge of acidic deposition to build an argument that either agrees or disagrees with this statement.

12. Describe some of the long-term effects acidic deposition might have within your local area.

13. Describe actions being taken by groups within your community to study or reduce emissions that could lead to acid deposition. Describe how the groups are determining whether these actions are having any effect.

14. Explain what takes place during chemical monitoring within the environment. Explain the importance of chemical data from monitoring stations to the study of acid deposition.

15. Define *biomonitoring*. Explain how biomonitoring is done within an ecosystem. Explain the importance of biomonitoring to the study of acid deposition.

16. Define *traditional ecological knowledge*. Explain the importance of traditional ecological knowledge to the study of acid deposition.

17. A student designs an experiment to investigate the effect of acid deposition on plants. Use the following information to answer questions 17.a. to 17.f.

Experimental Design
Obtain three healthy spider plants. Each plant will be watered daily, directly onto the soil, and using equal volumes of liquid. The first plant will be watered with a solution containing sulfuric acid that has a pH of 1; the second plant will be watered with a solution of ethanoic acid with a pH of 3; and the third plant will be watered with distilled water (pH 7). The plants will be observed each day for one week for signs of damage to leaves, loss of colour, and other changes to the appearance of the plant.

a. Predict some of the changes to the plants you think you will see during the experiment.

b. If you were able to perform chemical tests on the soil during the experiment, predict any changes you might expect to occur.

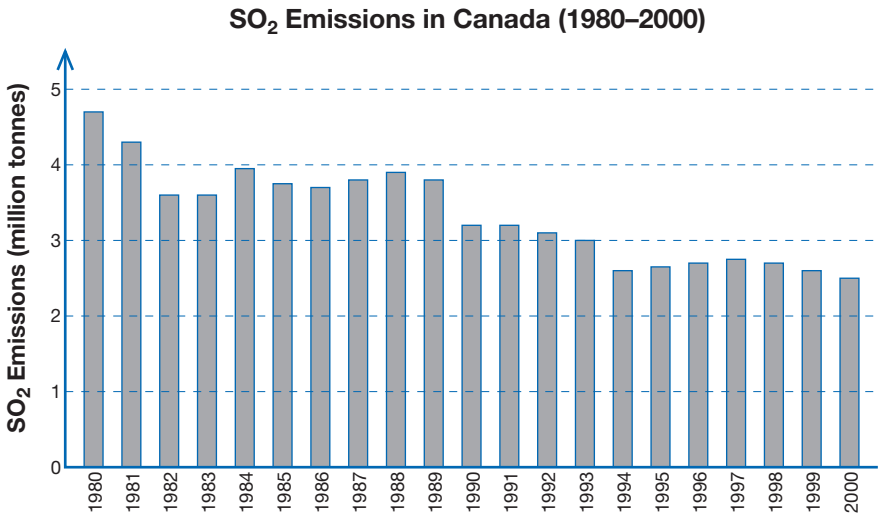
c. Predict the effect that a potting soil with a high buffering capacity could have on the results of the experiment.

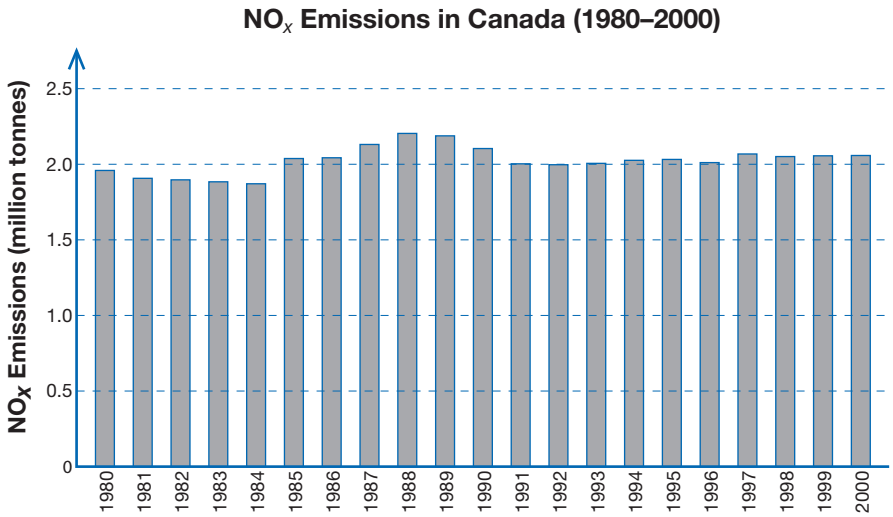
d. Identify the controlled variables in the experiment.

e. Identify the limitations of the experiment.

f. Describe any modifications to this experiment that could improve both reliability and validity.

18. Closely examine the graphs titled "SO_2 Emissions in Canada (1980–2000)" and "NO_x Emissions in Canada (1980–2000)."





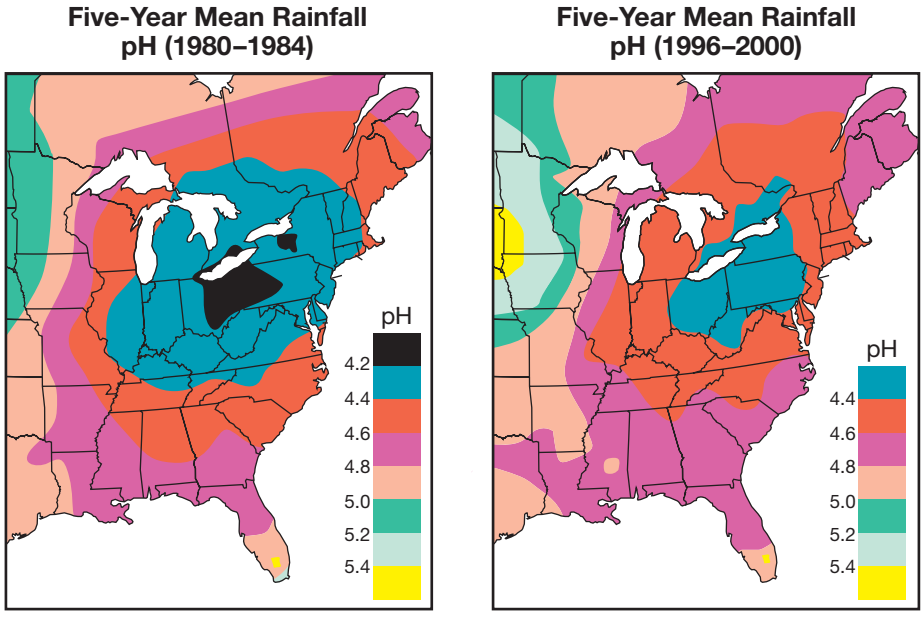
a. Determine the percentage change for each of SO_2 and NO_x from 1980 to 2000 in Canada.

b. Account for the trend shown on each of the graphs.

c. Predict the effect that the change in emissions would have on the pH of rainfall.

d. Explain why data for SO_2 and NO_x emissions from sources in the United States is important in developing a prediction regarding changes in the pH of rainfall in Canada.

e. Refer to the following maps.



Explain whether the data shown on these maps supports the predictions you made in your answer to question 18.c. What inference can you make from these maps regarding SO_2 and NO_x emissions in the United States over the time given?

f. Is it possible to use the maps depicting a five-year mean pH for rainfall to conclude that a reduction in SO_2 and NO_x emissions will reduce the severity of acid deposition? Support your answer.